PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Transmission Type Interference Filter

We, HITACHI LTD., a Japanese Body Corporate of, 4,1-chome, Marunouchi, Chiyoda-ku, Tokyo, Japan, do hereby declare that the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a transmission type interference filter and more particularly to a transmission type interference filter useful also in a far infra-red region.

Generally, a wavelength region over 25μ up to about 3 mm observable as light is called a far infra-red region. In spectrophotometry in a far infra-red region, a diffraction grating is used as dispersive element and a heat radiation source is generally employed as light source. The heat radiation source has such a property that the intensity of the radiation on a shorter wavelength side is larger than that of the radiation on a longer wavelength side and the diffraction grating has the property that when a monochromatic light based on the dispersion of the diffraction grating is to be taken out into a predetermined light path, unnecessary higher order diffraction light on the shorter wavelength side is taken out into the light path in superposition with said monochromatic light. Accordingly, it is important in spectrophotometry which employes the diffraction grating to eliminate said unnecessary higher order diffraction light on the shorter wavelength side.

For the elimination of the unnecessary light on the short wavelength side in spectrophotometry in a far infra-red region, a powder filter wherein a crystal powder such as ZnO, BeO, is mixed into a polyethylene film is considered to be the most effective at present. However, the powder filter suffers from the defect that the spectral transmittance curve does not rises sharply. As a filter wherein a spectral transmittance curve rises sharply, an interference filter is known. In such an interference filter alternate layers consisting of low refractive index layers and high refractive index layers are formed by vacuum deposition. Such an interference filter is expected to be effective not only as a cut-off filter which eliminates the short wavelength light, but also as a monochromatic filter wherein a spectral transmittance curve rises sharply. Though the interference filter is effective in wavelength regions including an infra-red region, however, it is practically quite difficult to make such a filter usable in a far infra-red region. In an interference filter for a far infra-red region, the thickness of each layer must be made large, but if the thickness of the respective layer is made large, each layer becomes liable to peel off due to the internal stress when the layer is made by vacuum deposition. Even if by chance the filter is well constructed, each layer peels off due to internal stress when practically used and the filter becomes useless.

According to one aspect of the invention there is provided a transmission type interference filter comprising a plurality of laminated layers wherein low refractive index layers and high refractive index layers are laminated closely alternately, and at least said low refractive index layers include transparent synthetic resin.

According to another aspect of the invention there is provided a method of fabricating a transmission type interference filter, comprising the steps of laminating a high refractive index layer with a low refractive index layer including transparent synthetic resin, and pressing together said layers in vacuum while heating.

According to yet a further aspect of the invention there is provided a method of fabricating a transmission type interference filter comprising the steps of laminating a high refractive index layer and a low refractive index layer and adhering said layers with adhesives.

An illustrative embodiment of the invention

will now be described with reference to the accompanying drawings; in which,

Fig. 1 is a diagram showing the composition of a transmission type interference filter according to an embodiment of this invention,

Fig. 2 shows a spectral transmittance curve obtained with the transmission type interference filter shown in Fig. 1, and

Fig. 3 shows a spectral transmittance curve obtained with a powder filter.

The transmission type interference filter shown in Fig. 1 consists of a first alternate layer F.A.L., a second alternate layer S.A.L. adhered to the right surface of said F.A.L, and a matching layer M.L. adhered to the left surface of said F.A.L. The M.L. may be adhered to the right surface of the S.A.L. In said F.A.L., high refractive index layers H and low refractive index layers L are laminated closely alternately, and in said S.A.L. also, high refractive index layers h and low refractive index layers l are laminated closely alternately. The high refractive index layers H, h are made of polyethylene including Ge powder at a rate of 91% in weight (refractive index $n=3.0$) and the low refractive index layers L, l and the matching layer M.L. are formed exclusively of polyethylene (refractive index $n=1.46$). The optical thickness nd (n: refractive index, d: geometrical thickness) of H, L is $\lambda_o/4$ ($\lambda_o=80\mu$), the optical thickness of h, l is $\lambda 1/4$ ($\lambda 1=50\mu$), and that of M, l is $\lambda_o/8$.

The transmission type interference filter shown in Fig. 1 is fabricated in the following way. A polyethylene plate is inserted between two revolving rollers and said two revolving rollers are rotated while heating said polyethylene plate to about 120°C. As the polyethylene plate is softened, the plate adheres to one of the revolving rollers. Then, Ge powder (at a rate of 91% in weight) is sprinkled over said softened polyethylene and said polyethylene and said Ge powder are sufficiently mixed with a bamboo spatula while said revolving rollers are rotating. After they are uniformly mixed, heating is stopped. After a while, the polyethylene hardens. Then, the revolving rollers are stopped. In this way, high refractive index layers H, h wherein $n=3.0$ are provided. The thickness of H, h is determined by the gap between the two revolving rollers. On the other hand, though the low refractive index layers L, l contain nothing but polyethylene, said two rollers are used to provide the optical thickness thereof $\lambda_o/4$, and $\lambda_1/4$. Naturally, it is possible to use polyethylene plates available on the market since polyethylene plates of various thickness are on the market. Since the matching layer M.L. is made only of polyethylene, it is possible to use polyethylene plates available on the market or to make the optical thickness of the plate $\lambda_o/8$ by using the two rollers as described hereinabove.

Then, the matching layer M.L., high refractive index layers H, h, and low refractive index layers L, l must be adhered in the order shown in Fig. 1. In order to do this, "a heating-press method" is employed in this invention. Namely, the matching layer M.L., the high refractive index layers H, h, and the low refractive index layers L, l are laminated in the order shown in Fig. 1, placed in a vacuum of the order of 10^{-3} mmHg, heated to about 100°C. to cause adhesion and applied with a pressure of about 10 kg/cm^2 for about 10 minutes. Then, the layers completely adhere to each other. Thus, a transmission type interference filter as shown in Fig. 1 is provided. When such a filter was subjected to practical use for a long time, it was verified by the present Inventors that peel-off of the layer once adhered did not take place and that the property as an interference filter was preserved.

The spectral transmittance curve obtained with the interference filter shown in Fig. 1 is shown in Fig. 2. Fig. 3 shows a spectral transmittance curve obtained with a powder filter. The powder filter used for obtaining the characteristics shown in Fig. 3 is formed by mixing CaF_2 and LiF each at a rate of 10% in weight into polyethylene.

Comparison of Fig. 2 and Fig. 3 indicates that the unnecessary light in a short wavelength region is absent in Fig. 2 and the spectral transmittance curve rises in extreme sharply.

In Fig. 1, the F.A.L. has an opaque region at about $65\mu\sim97\mu$ and has another opaque region below about 40 due to the light scattering effect of Ge powder mixed thereinto, but it has a transparent region at about $40\mu\sim65\mu$. However, the region of $40\mu\sim65\mu$ is made opaque due to the presence of the S.A.L. Further, when the M.L. is absent, a relatively large ripple of the spectral transmittance curve shown in Fig. 2 appears in a transparent region over 97μ, but said ripple is diminished by the M.L. having an optical thickness of $\lambda_o/8$. Though the M.L. is adhered to the left surface of the F.A.L. in Fig. 1, the same effect can be obtained by adhering a matching layer of $\lambda_1/8$ in optical thickness to the right surface of the S.A.L.

In Fig. 2, the cutoff wavelength is present at about 97μ. However, generally in a transmission type interference filter comprising an alternate layer consisting of high refractive index layers and low refractive index layers, the transmittance of light having a wavelength λ approaches zero when the optical thickness nd of each layer satisfies the condition $nd=\lambda/4$, and the transmittance approaches zero more and more as the number of layers increases. Therefore, said cutoff wavelength can be changed by varying the optical thickness nd of said respective layers. In practice, the wavelength λ at which transmittance becomes

zero has a width $\Delta\lambda$. Namely, when $nd=\lambda/4$, not only the transmittance of light of wavelength λ approaches zero, but the transmittance of light of wavelengths lying in the width $\Delta\lambda$ including λ approaches zero. If said $\Delta\lambda$ is named a cut width, the cut width becomes larger as the difference in refractive index Δn between high refractive index layers and low refractive index layers increases. Further, as the number of layers is increased, the transmittance of light lying in the range $\Delta\lambda$ approaches more closely to zero and the spectral transmittance curve comes to rise more sharply.

The transmission type interference filter shown in Fig. 3 is a cut off filter which cuts short-wavelength light in its function, but a narrow bandpass filter can be fabricated by suitably selecting construction of the respective layers.

Though an embodiment of this invention is shown in Fig. 1, various changes or modifications may be made. Namely,

(1) As a material for the low refractive index layers L, *l*, transparent synthetic resin, e.g. polymers like polypropylene, polycarbonate, polyvinylidene chloride, polyvinyl chloride, or polyethylene terephthalate, polystyrene, polyester, epoxy resin and the like can be used instead of polyethylene. The refractive index of these mattrials is about 1.5. As a material for the high refractive index layers H, h, the same materials as described hereinabove can be used such as polyethylene into which a material of a high refractive index such as Ge, is mixed with a Si containing substance or Ge can be used without mixing a material of a high refractive index like Te, ZnS, etc. The former has a refractive index $n=3.0$ and the latter, $n=4.0$.

(2) The low refractive index layers L, *l* can be made by mixing at least one of low refractive index materials like LiF, CaF_2, MgF_2, NaCl, KBr, BaF_2 into said transparent synthetic resin. The refractive index of these low refractive index materials is less than 1.5.

(3) In addition to a simple substance of Si, Ge, a material made by mixing at least one of the high refractive index materials Si, Ge, Te, ZnS, TlCl, TlBr, or TlI, into said transparent synthetic resin can be used for the high refractive index layers H, h. The refractive index of these high refractive index materials is more than 2.0.

(4) Only two alternate layers F.A.L. and S.A.L. are present in Fig. 1, but the number thereof can be increased if necessary.

(5) Though the filter in Fig. 1 is made by a so-called heating press method, it is possible, in practice, to form the filter by an adhesion method using adhesive like epoxy adhesives. However, it is more preferable to use a heating press method, since the thickness of the adhered layers sensitively influences the spectral transmittance curve thereof and also the technique of fabrication is not necessarily simple.

(6) Though the pressure was about 10 kg/cm^2 and the heating temperature was about 100°C. when the filter shown in Fig. 1 was fabricated by a heating-press method, these quantities are not fixed, but can be changed as required.

In the invention the transparent synthetic resin such as polyethylene, polypropylene, polyvinylidene chloride, polyethylene terephthalate, polystyrene, polyester, polycarbonate, epoxy resin, polyoxymethylene, etc. may be used as a material for respective layers having low refractive index and as a suspended material for respective layers containing crystal powders may be used such as Si, Ge, TlCl, KBr, KCL, NaCl, KI, TlI, etc.

Thermoset resin and thermoplastic resin are utilized equivalently in the invention when the synthetic resins have desirable light transmittance in far infra-red region.

As explained in the foregoing, when the transparent synthetic resin is used as the respective layers according to the invention, a plurality of the synthetic resin layers and a plurality of the high refractive index layers are laminated closely alternately by means of heat-pressing or adhering so as to form a configuration of alternative high and low refractive index layers, in which the synthetic resin layers as low refractive index layers may contain the low refractive index powders or maybe not contain them, and the high refractive index layers may be not only made of plates or sheets of the high refractive index material such as Si, Ge, etc., but also made of mixtures of the high refractive powder and the transparent synthetic resin.

It will be apparent that the desired transmission type interference filter of the invention can be made by alternately providing to a coating of liquefied or slurried synthetic resin as low refractive index material and the high refractive index material respectively.

When the synthetic resin is used as suspending material of the crystal powder, the filter of the invention is also fabricated by painting liquid or slurry of the above-mentioned synthetic resin alternately with mixtures composed of the synthetic resin and the powder so as to form alternate laminated layers of high and low refractive index layers.

WHAT WE CLAIM IS:—

1. A transmission type interference filter comprising a plurality of laminated layers wherein low refractive index layers and high refractive index layers are laminated closely alternately, and at least said low refractive index layers include transparent synthetic resin.

2. A filter according to Claim 1, wherein said resin is thermoplastic resin.

3. A filter according to Claim 1 or 2

wherein said low refractive index layers further include material having a low refractive index mixed into the transparent synthetic resin.

4. A filter according to any one of the preceding claims, wherein said high refractive index layers include transparent synthetic resin.

5. A filter according to Claim 4, wherein said high refractive index layers include a material having a high refractive index mixed into the transparent resin.

6. A filter according to any one of claims 1, 2 and 3, wherein said high refractive index layers are made of material selected from Si and Ge.

7. A filter according to any one of the preceding claims, wherein said synthetic resin is selected from the group consisting of polyethylene, polypropylene, polystyrene, and polyvinyl chloride.

8. A filter according to Claim 3, wherein said low refractive index material contains at least one of LiF, CaF_2, MgF_2, NaCl, KBr, BaF_2.

9. A filter according to Claim 4, wherein said low and high refractive index layer transparent synthetic resins are thermoplastic resins.

10. A filter according to Claim 5, wherein said high refractive index material contains at least one of Te, Ge, Si, ZnS, TlCl, TlBr and TlI.

11. A filter according to Claim 9, wherein said thermoplastic resin is selected from polyethylene, polypropylene, polystyrene, and polyvinyl chloride.

12. A transmission type interference filter comprising at least two groups of closely laminated alternate layers, wherein each of said groups of alternate layers includes alternately adhered low refractive index layers and high refractive index layers, the optical thickness of each layer in one of said groups of alternate layers is different from that of each layer in the other group of alternate layers and each low refractive index layer of said groups of alternate layers includes transparent synthetic resin.

13. A filter according to Claim 12, wherein said low refractive index layers include thermoplastic resin.

14. A filter according to Claim 12, wherein said low refractive index layers include thermoplastic resin and a low refractive index powder mixed into said thermoplastic resin.

15. A filter according to claim 12, wherein said high refractive index layers include transparent synthetic resin.

16. A filter according to Claim 12, wherein said high refractive index layers include thermoplastic resin and a high refractive index material mixed into said thermoplastic resin.

17. A filter according to Claim 12, wherein said high refractive index layer is made of a material chosen from Si and Ge.

18. A filter according to Claim 12 further comprising a matching layer adhered closely to one of said groups of alternate layers.

19. A filter according to Claim 14, wherein said low refractive index powder has a refractive index less than 1.5.

20. A filter according to Claim 16, wherein the refractive index of high high refractive index layer is more than 2.0.

21. A filter according to Claim 18, wherein said matching layer is made of thermoplastic resin.

22. A method of fabricating a transmission type interference filter, comprising the steps of laminating a high refractive index layer with a low refractive index layer including transparent synthetic resin, and pressing together said layers in vacuum while heating.

23. A method of fabricating a transmission type interference filter comprising the steps of laminating a high refractive index layer and a low refractive index layer and adhering said layers with adhesives.

24. A transmission type interference filter substantially as described with reference to Figure 1 of the accompanying drawings.

25. A method of making a transmission type interference filter substantially as described with reference to Figure 1 of the accompanying drawings.

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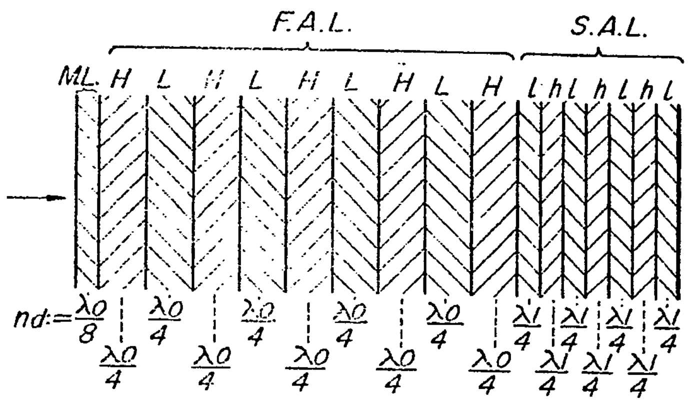
2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1



$\lambda 0 = 80\mu$
$\lambda 1 = 50\mu$

H, h : Ge POWDER IN POLYETHYLENE (91%) ($n = 3\cdot0$)
L, l : POLYETHYLENE ($n = 1.46$)

1198904 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

FIG. 2

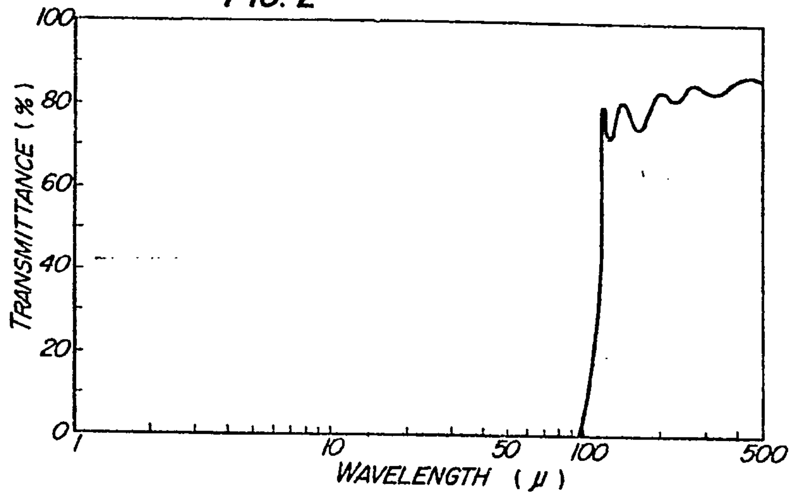


FIG. 3